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POWER SYSTEMS RELIABILITY

IEEE Std 3006.2™-2016

Recommended Practice forEvaluating the Reliability of Existing Industrial and Commercial Power Systems

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IEEE Recommended Practice for Evaluating the Reliability of Existing Industrial and Commercial Power Systems

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Abstract: Described in this recommended practice are criteria for evaluating the reliability of existing industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Keywords: availability, IEEE 3006.2™, reliability, reliability analysis

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Introduction

This introduction is not part of IEEE Std 3006.2™-2016, IEEE Recommended Practice for Evaluating the Reliability of Existing Industrial and Commercial Power Systems.

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This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material in the 13 IEEE Color Books will be included in a series of new standards—the most significant of which will be a new standard, IEEE Std 3000™, IEEE Recommended Practice for the Engineering of Industrial and Commercial Power Systems. The new standard will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional dot standards, organized into the following categories, will provide in-depth treatment of many of the topics introduced by IEEE Std 3000™:

— Power Systems Design (3001 series)
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— Power Systems Grounding (3003 series)
— Protection and Coordination (3004 series)
— Emergency, Standby Power, and Energy Management Systems (3005 series)
— Power Systems Reliability (3006 series)
— Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

The material in this recommended practice largely comes from Chapter 4 of IEEE Std 493™ (*IEEE Gold Book*™).

IEEE Std 3006.2™

This publication provides a recommended practice for the power engineer. It is likely to be of greatest value to the power-oriented engineer with design experience. It can also be an aid to all engineers responsible for comparing different designs and assessing the potential performance of the system. However, it is not intended as a replacement for the many excellent engineering texts and handbooks commonly in use, nor is it detailed enough to be a design manual. It should be considered a guide and general reference for commercial and industrial facilities.

Tables, charts, and other information that have been extracted from codes, standards, and other technical literature are included in this publication. Their inclusion is for illustrative purposes; where technical accuracy is important, the latest version of the referenced document should be consulted to assure use of complete, up-to-date, and accurate information.

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1. Scope

This recommended practice describes how to evaluate the reliability of existing industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the design of industrial and commercial power systems. It contains recommendations for assessing power system conditions and assembling the data required for full reliability calculations for large or critical facilities as well as recommendations for inspection, maintenance, and engineering activities that will benefit smaller or less critical facilities.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 141™, IEEE Recommended Practice for Electric Power Distribution for Industrial plants (IEEE Red Book™).[1,2]

[1]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).
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IEEE Std 242™, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*™).

IEEE Std 315™, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams.

IEEE Std 493™, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (*IEEE Gold Book*™).

IEEE Std 1366™, IEEE Guide for Electric Power Distribution Reliability Indices.

IEEE Std 3006.5™, IEEE Recommended Practice for Use of Probability Methods for Conducting Reliability Analysis of Industrial and Commercial Power Systems.

IEEE Std 3006.7™, IEEE Recommended Practice for the Determining the of Reliability of 7×24 Continuous Power Systems in Industrial and Commercial Facilities.

IEEE Std 3007.1™, Recommended Practice for the Operation and Management of Industrial and Commercial Power Systems.

IEEE Std 3007.2™, Recommended Practice for the Maintenance of Industrial and Commercial Power Systems.

3. Definitions and acronyms

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[3]

For definitions of terms pertaining to power system reliability used in this standard, refer to IEEE Std 3006.5.

3.2 Acronyms

ANSI	American National Standards Association
FMEA	failure modes and effects analysis
HVAC	heating, ventilation, and air conditioning
IT	information technology
NEMA	National Electrical Manufacturers Association
NETA	InterNational Electrical Testing Association
O&M	operations and maintenance
PPM	preventive and predictive maintenance
UPS	uninterruptible power supply (system)

4. General

Traditionally, efforts to improve the reliability of electrical service within an industrial or commercial facility with critical power requirements have focused on increasing the reliability of the electric utility supply. Fa-

[3]*IEEE Standards Dictionary Online* subscription is available at: http://ieeexplore.ieee.org/xpls/dictionary.jsp.

cility engineers may be unable to improve the reliability of the utility supply, such improvement may be very costly, and will have no impact on outages resulting from internal failures. As a result, they must also focus their attention on critical areas within the facility power system. A logical approach to the analysis of options available in the electrical system (in terms of both utility supply and facility distribution) will lead to the greatest reliability improvement for the least cost. In many instances, the user can improve reliability without capital investment by making the proper inquiries and acting upon the results.

A thorough and properly integrated investigation of the entire electric system will pinpoint the components or subsystems having unacceptable reliability. Some important general inquiries follow. Many of these questions apply to the utility and the industrial or commercial facility distribution systems.

a) How is the system operated under normal and contingency conditions?
b) What are the age and physical condition of the electric system components?
c) What are the effects of faults that occur at different points in the system on the critical loads?
d) What is the probability of failure and its expected duration for each of the components or sub-systems of the system?
e) Are critical loads, defined as those necessary to sustain the mission of the facility, segregated from non-critical loads?
f) Are there hazards other than mission impact, such as fire or life safety, associated with interruption of power?
g) What duration of power interruption will affect the mission of the facility, and what is the cost of that impact? (That is, will momentary or short-duration interruptions cost production dollars or merely be an inconvenience?)
h) What power quality criteria must the electrical system meet to support the facility mission?
i) Is system documentation, such as single-line diagrams and short-circuit and coordination studies, up to date?
j) Are the proper operations and maintenance policies and procedures in place to support achieving the designed-in reliability of the system?

Considering and acting correctly upon the answers to these questions can improve reliability.

5. Evaluation methodology—overview

Evaluation of the reliability of an existing electrical system should include review of the system at a number of levels, each of which are discussed in more detail in subsequent clauses of this standard.

5.1 Utility supply

The 1974 survey of electrical equipment reliability in industrial plants (see IEEE Committee Report [B2])[4], parts of which are available as Annex A and Annex B of IEEE Std 493, and subsequent investigations showed the utility supply to be the largest single component affecting the reliability of an industrial plant. A power quality survey of 112 industrial and commercial sites in North America conducted in 1995 [B1] identified supply interruptions as likely responsible for the majority of adverse impacts to computers and other electronic equipment within the facilities.

[4]The numbers in brackets correspond to those of the bibliography in Annex A.

Most customers simply "hook up" to the utility system and do not fully recognize that their reliability requirements may affect how the utility supplies them. A utility is constrained by the system available at the customer site and the investment that can be justified by the anticipated revenue. However, most utilities are willing to discuss the supply options that are available to their customers. Many times, an option is available (sometimes with financial sharing between the user and the utility) that will meet the reliability needs of a specific facility.

5.2 Configuration

The system configuration determines the inherent reliability that is obtainable without adding or rearranging components. The first level of analysis should address this, using the single-line diagram to identify vulnerabilities due to single paths, single points of failure, capacity shortfalls, etc.

5.3 Control and protection

One level below the configuration is the control and protection system. Even if the power system configuration is adequate to provide the required level of reliability, failure of the control and protection system can compromise its performance. Automatic controls, such as bus transfer schemes and standby generator control systems, must function properly to make alternate paths or sources of power available to the load on failure of the primary source. Protective devices must be selectively coordinated to isolate the load from faulted portions of the system and prevent faults on one path or in one portion of the system from causing interruption of multiple paths or sources.

5.4 Physical installation

Review the physical configuration and location of electrical equipment. Is the equipment adequately protected from physical damage and environmental hazards? Is physical segregation provided between redundant paths so that a failure of one piece of equipment cannot readily propagate to redundant circuits or equipment?

5.5 Operations and maintenance

Operations and maintenance (O&M) practices are critical to achieving the designed-in reliability of the system. Effective commissioning helps assure that control and protection systems function per design. Preventive maintenance can reduce failure rates, and an adequate level of spare parts stocking can reduce repair times when failures do occur. Effective policies, procedures, documentation, and training of O&M personnel reduce outages due to human activity and improve operator response time when failures occur. (Refer to IEEE Std 3007.1 and IEEE Std 3007.2.)

6. Utility supply availability

Loss of utility power will cause an interruption to critical areas unless alternate power sources are available. Therefore, the reliability of the utility supply is of paramount importance to the facility engineer. Different facilities and even different circuits within the same facility vary in their response to loss of power. In some cases, a 10-min power interruption will not significantly affect operations. In other cases, a 10-ms interruption will cause significant impact. The engineer should assess the operational vulnerability and convey the facility reliability and power quality requirements to the local utility, as well as to their own management. (See 6.3 and 6.4 of IEEE Std 3006.1 for information on economic loss versus unavailability of incoming power.)

6.1 Use of historical data

For existing circuits and substations, the utility should be able to supply a listing of the frequency, type, and duration of power interruptions over the preceding three to five year period. They should also be able to predict the future average performance based on historical data and planned construction projects. For new circuits,

the utility may be able to supply the historical performance of other circuits of similar length and construction near the facility under investigation. Refer to IEEE Std 1366 for definitions of reliability terms commonly used by utilities and USDA Bulletin 1703A-119 [B8] for reporting requirements for rural utilities. The user of utility-supplied interruption rate information is cautioned that the definition of interruption may need to be clarified with the utility. Due to reporting agreements with their regulatory agencies, some utilities may not consider events lasting five s or less, or recloser operations that do not result in a lockout, to be interruptions.

An alternative is to obtain a one-line diagram or system map of the utility supply system and independently evaluate its availability. Absent data for the specific system, IEEE Std 3006.8 includes average utility availability data.

Compare the utility's history of interruptions with recorded dollar losses in assessing process vulnerability. By assigning a dollar loss to each interruption, it may be possible to determine a relationship between the duration of a power loss and monetary loss for a particular facility. When the actual outage cost differs from the predicted cost, the cause of the deviation should be determined. For example, a 15-min power loss at a shift change will be less costly than one during peak production. With a refined cost formula in hand, reevaluate the cost of available options against the savings from increased reliability or availability.

Occasionally a facility experiences problems at times other than during a recorded interruption. These problems may indicate power quality deviations such as voltage sags or voltage swells that are difficult to trace [Refer to IEEE Std 141 (*IEEE Red Book*™) for definitions of acceptable voltage ranges]. With problems such as these, it is necessary to begin recording the exact date and time of these occurrences, and ask the utility to search for faults or other system disturbances at or near those times. It is wise to convey the times to the utility reasonably soon after the problem occurs. Unless these problems are significant in terms of dollars lost, safety, or frequency, it is not reasonable to pursue the cause of voltage dips since they are a natural phenomenon in the expansive system operated by a utility. Large motors starting, welder or electric furnace inrush, or faults on other distribution feeders supplied by the same substation bus as facility feeders can cause voltage sags.

6.2 Operational issues

It is also reasonable to discuss contingency conditions with the utility and to weigh their answers in any supply decision. A list of questions includes the following:

a) What are the continuous and short-term emergency capacities of the existing services?

b) How will projected load growth affect the capacity and reliability of these services?

c) Based on historical data or utility estimates, what are the anticipated response and restoration times for various types of events or failures on the utility system, including:

   1) Distribution feeder failure, overhead or underground

   2) Substation bus fault

   3) Substation transformer failure

   4) Transmission or sub-transmission line outage

d) How do these anticipated restoration times vary seasonally and during inclement weather or widespread events?

e) Are procedures in place within the facility for responding to outages, coordinating with the utility, and taking required actions to restore power, and do they provide a basis for accurately estimating restoration times for the various types of outages that can occur?

f) Is a more reliable utility source available, and what is the cost of extending it to the facility?

1) Is this additional source from the same substation and bus, from a different bus at the same substation, or from another substation?

2) What is the probability (frequency and duration) of both the main and the backup source failing simultaneously?

3) How much does the additional or alternate source improve reliability?

g) Will the utility's protective equipment coordinate with the facility's protective equipment? If not, what is the potential impact of mis-coordination and how can it be resolved?

h) What are the available short-circuit currents and utility protective device characteristics and settings at each service, are there plans to change the system that will affect these, and is there a process to assure notification of the customer when such changes occur?

These questions may not apply to all facilities, so choose among them for specific user requirements.

6.3 Multiple sources

When providing multiple sources to increase reliability, it is important to consider whether to operate the sources in parallel or to isolate them with an automatic transfer control scheme to switch from a failed source to the alternate source. If the sources are isolated, a fault on one source will affect only the parts of the facility served from that source, and the duration of the outage to those loads depends on the timing of the automatic transfer scheme, but is typically at least several seconds. If the sources are operated in parallel, both sources will experience a voltage dip for a fault on either source, affecting all of the facility, but with a duration limited to the clearing time of the faulted circuit. Which of these conditions is preferable depends on the type of loads and the details of the electrical system of the specific facility. For the most critical loads, application of a spot network system, in which multiple step-down transformers served by different primary feeders operate in parallel through secondary network protectors, can provide high reliability, although at a correspondingly high cost.

The degree of independence of the sources is also important to determining the available improvement in reliability. Multiple utility distribution feeders should preferably come from different substations. If this is impractical or too costly, they should at least originate from different buses within the same substation, so that voltage dips from faults on other distribution feeders, or substation bus outages, do not affect multiple feeders. Even feeders from different substations are likely to simultaneously experience the momentary voltage dips associated with transmission or subtransmission system faults.

Verify the available standby capacity on each source that the utility is willing to dedicate to the facility. It is common for utilities to use multiple interties to permit distribution feeders to back one another up. A feeder that has adequate capacity to carry the entire facility load under normal conditions may not have that capacity available if there have been multiple feeder outages and it is being used to back up other feeders.

6.4 Power quality considerations

Power system reliability and availability calculations do not generally consider power quality, but its effects on sensitive loads may have the same impact on the facility as outages and facility operators often consider it a reliability-related concern.

If utility events other than extended interruptions, such as voltage sags or momentary interruptions, adversely affect the load, a range of solutions can be considered. Underground circuits, dedicated underground circuits, dedicated substation buses, and even dedicated substations provide increasing degrees of protection from these events, although generally with increasing costs.

Surge arrestors usually provide the major source of protection from transient over-voltages on utility circuits. On the customer side of the meter, this protection is normally provided by a combination of surge protective devices and isolation transformers. Where the loads are very sensitive to disruption, a double conversion UPS system provides complete isolation.

7. Configuration

7.1 Where to begin—the one-line diagram

The "blueprint" for electrical analysis is the one-line diagram. An up-to-date one-line diagram is essential for the facility electrical engineer. It is the "road map" of the electric system. In fact, an accurate and up-to-date one-line diagram should exist (or be prepared) even if the ensuing analysis is not done.

The one-line diagram should begin at the incoming power supply. Use standard IEEE symbols to represent electrical components (see IEEE Std 315). It is usually impractical to show all circuits in a facility on a single schematic, so the initial one-line diagram should show only major components, circuits, and loads. Analysis that is more detailed may be required in critical areas, and additional one-line diagrams should be prepared for these areas as required.

For an example one-line diagram of a typical industrial power system, refer to IEEE Std 141 (*IEEE Red Book*™). For an example of a one-line diagram annotated for reliability analysis, refer to IEEE Std 493 (*IEEE Gold Book*™).

The one-line diagram should include at least the following information:

a) Utility connections: voltage, capacity and rating basis (continuous versus short-term emergency), utility circuit name or number, and substation of origin.

b) Generators: ratings (alternator and prime mover), type of prime mover, grounding means.

c) Large motors: ratings, load served, and starting method.

d) Switchgear: bus ratings, configuration, switching and protection device types and ratings. Indicate physical boundaries of individual lineups.

e) Power transformers: ratings, winding connections, and grounding means.

f) Protective relays: ANSI device designation, instrument transformer connections, tripping and blocking logic. If multi-function relays are used, indicate grouping of protection elements within individual relays.

g) Description of mechanical or electrical interlocks that restrict operation such as preventing closed-transition switching or paralleling of sources.

h) Description of control schemes such as automatic bus transfer, remote operation, etc.

i) Potential transformers: ratio, connection, accuracy class.

j) Current transformers: ratio, connection, accuracy class.

k) Control power transformers: ratings and function.

l) Circuits: Installation method (overhead, conduit, underground, etc.), conductor material, insulation type, voltage rating, length, and splice and termination types and locations.

m) Unit substations and load centers: equipment types, ratings, and designation of load served.

For numerical reliability analysis, identify the individual components and represent on the one-line diagram the physical as well as electrical connections within the system. For example, it makes a difference in calcula-

tion whether a connection between two cables occurs by “double-lugging” two sets of terminations at a switch or circuit breaker, by splicing the cables in a manhole, or by using load-break junctions in an aboveground cabinet. If space permits, additional information such as available short-circuit currents at each bus, date of equipment installation, and the reliability data for the individual components may be included. Including failure rate and duration information for every component on a one-line uses up white space very quickly; a recommended alternative is to develop a table of the component data applicable to the system with a numerical or alphabetical key for each entry and show only the appropriate key for each component on the one-line diagram. It is preferable to use historical reliability data for the specific facility if available and statistically valid.

The one-line diagram may show planned future as well as current feeder and substation loads. In most facilities, load changes occur in small increments without observed effect until some part of the system becomes overloaded or underloaded. Loads may have been added without appropriate modification of the existing settings on the associated upstream circuit breakers. In addition, original designs may not have included special attention to the critical loads. Include the following information on the one-line diagram:

a) The scope of the existing system and planned revisions, noting the characteristics and locations of the added loads.
b) Critical areas of the system.
c) Component reliability data, so that the reliability performance of the revised system can be analyzed.

For complex systems, it is beneficial to create an overall one-line diagram at a reduced level of detail that permits viewing the entire system topology on a single sheet. Include the utility connections, switchgear, feeders, substations and load centers, tie circuits, and major equipment such as generators and large motors or other concentrated loads on the overall diagram. This can be supplemented by more detailed relaying and metering diagrams of switchgear and additional one-line diagrams of specific areas. After completion of these diagrams, a comprehensive analysis can begin. The inspection described in Clause 9 may be performed during the data gathering process.

The one-line diagram is a picture of an ever-changing electric system. Sustain the benefits of the effort expended in preparing the diagram and analyzing the system by providing a means to capture new pictures of the system with actual or proposed changes. All proposals should trigger reliability scrutiny as well as one-line diagram updates, and their effect on the total system analyzed before approval. This process not only maintains the integrity of the system, but may minimize expense by more effectively utilizing existing facilities. It should be noted that other important system analyses such as short-circuit studies and arc flash hazard analysis are required by codes and standards to be updated as system modifications occur; maintaining an up-to-date reliability analysis model should be integrated into the facility’s overall change-management policies and procedures that address these other concerns.

7.2 Analysis

Following completion of the facility one-line diagram, conduct an analysis of the system to identify design problems. If any parts of the system cannot meet their basic functions of carrying the load and safely interrupting faults, these conditions should be addressed prior to or simultaneously with detailed reliability analysis.

a) Evaluate the capacity and loading of the services, feeders, and other components of the system to verify that loads do not exceed ratings under either normal or contingency operating conditions. A software-based load flow and voltage drop study may be required to verify that voltages at the loads remain within acceptable limits under conditions of contingency operation, transformer inrush, and large motor starting.
b) Evaluate the available short circuit currents throughout the system and verify that all equipment has adequate withstand and interrupting ratings for the duty. If a software-based power system model of

the system does not exist, use manual calculations with conservative assumptions; perform a more detailed analysis if these calculations identify conditions where the duty is within 10% of the rating.

c) Inspect the configuration for single points of failure, components or circuits whose failure or interruption will simultaneously interrupt multiple paths between the source(s) and loads, or simultaneously interrupt power to redundant equipment.

After determining that the design of the system is sound, or identifying and resolving capacity or ratings issues, perform a failure modes and effects analysis (FMEA) on the system. This process identifies the potential failure modes of each component of the system and their effect on the critical loads. Detailed information on failure modes of electrical equipment is available in IEEE Std 3006.5. The most important components and failure modes to consider will be those having either a high probability of failure or a long repair time, or both.

Conducting an FMEA requires knowledge of not only the electrical system, but also the manufacturing processes or operations of the facility as well. Equipment intended to be redundant from a process or operations standpoint should be served from segregated parts of the electrical system, and non-redundant equipment whose failure could affect multiple processes or critical loads should be provided with alternate sources of supply.

Having identified critical components and failure modes, the next step is to conceive measures to mitigate the effects of these on the loads. These may include:

a) Increasing the reliability of the component through replacement, more frequent preventive maintenance, or predictive maintenance techniques.

b) Reducing the repair time through advance development of response plans, stocking of spares, pre-arranged emergency response contracts, or other means.

c) Modifying the system to provide redundant components, alternate circuit paths, or automatic restoration processes.

Many facilities have on-site generators to back up utility power. This will raise the availability of electrical power for those loads served by the generator. It may also raise the reliability, depending on how you define failure for the facility. For example, if loss of power while the generator starts and transfers to pick the load back up is acceptable, the facility will have increased availability and reliability for the loads backed up by the generator. If loss of power while the generator starts will cause a failure, such as with most IT equipment rooms, an uninterruptable power supply (UPS) system is also required to improve the reliability.

The above example shows that improving the reliability of the existing power system may include analysis of several systems and verification that all of the critical loads are served by the proper system. An example of this is to assure that the fuel transfer system for the standby generator is served by the generator.

When evaluating critical facilities, such as data centers, it is often worthwhile to compare the one-line drawing for the systems in the facility with examples given in IEEE Std 3006.7 to see how well the critical systems have been designed.

It is at this point in the process that quantitative reliability analysis using the reliability data collected during preparation of the system one-line diagram may be useful for comparing the degree of improvement in reliability obtainable from different options. Refer to IEEE Std 3006.5 for details on conducting reliability analysis.

8. Assessing control and protection

The one-line diagram and other documents described in 7.1 provide the basic information required for an assessment of whether the control and protection system design will support the reliability level that the system

configuration is intended to provide. Identify protective relays by ANSI device type number; show instrument transformer ratios and connections and indicate tripping logic either by dashed lines between devices or by a tripping schedule. For complicated systems, separate instrumentation and relaying one-line diagrams may be required to supplement the overall one-line diagrams.

Perform a protective device coordination analysis [refer to IEEE Std 242 (*IEEE Buff Book*™)]. Protection should meet three objectives:

a) Sensitive and high-speed clearing to minimize the depth and duration of voltage dips associated with faults.
b) Selective coordination to limit the outage to the affected portion of the system.
c) Security against nuisance tripping due to load characteristics and system transients.

Consider the following when reviewing the results of the coordination study:

a) Are the circuit breakers, relays, and fuses properly set and properly rated for the current load levels?
b) Is there any new load that has reduced circuit reliability (or increased vulnerability)?
c) Are there any areas where coordination is not selective? Can different device settings correct this, or is it unavoidable? If unavoidable, assess the impact of nonselective tripping. If the affected circuits are not important, it may be acceptable. If mis-coordination affects critical circuits, consider corrective measures such as redistributing loads or relay upgrades.
d) Are both primary and secondary or backup protection provided so that a circuit breaker or relay failure does not leave equipment unprotected or require backup tripping of an upstream device affecting redundant circuits?

Review the reliability of switchgear control systems providing automatic response to outages and restoration of service through an alternate source or standby generation. If a single control system is associated with redundant electrical sources or circuits, control system vulnerabilities may compromise the reliability built into the power system. Control system review may address the following:

— Is the design fail-safe, such that processor failure or other component failure will leave the electrical system “as is,” or can control failures cause unwanted circuit breaker operations?
— Are redundant or highly reliable control power sources used?
— Is the control system provided with effective transient voltage suppression and properly designed grounding to prevent misoperation due to lightning or switching surges?
— Are there redundant processors or provisions for manual operation in the event of processor failure?
— If the control system has communication connections outside the facility, are best practices for cyber-security in place?
— Are operator control layouts designed to minimize human error through status feedback, color coding, mimic buses, clear labeling, etc.?
— Was the control system thoroughly commissioned and is it regularly tested?
— Are complete written sequences of operation available and familiar to the personnel responsible for operating and maintaining the system?
— Are the complete schematic and wiring diagrams available?

9. Physical assessment

A thorough inspection of the physical condition of a plant's distribution system, implemented on a continual basis, can improve reliability. All systems serving critical loads or processes should be part of a comprehensive preventive and predictive maintenance (PPM) program, which combines periodic visual inspections of equipment with mechanical and electrical testing to identify and correct deteriorating conditions before they result in unscheduled outages. If such a program has not been in place, a thorough initial round of inspection and testing can provide the following benefits:

a) Immediate identification of conditions that may cause failures in the short term.

b) Indication of the general conditions of maintenance of the system for selecting failure rate multipliers in reliability calculations as discussed in Clause 6 of IEEE Std 3006.3.

c) Baseline testing values for trend monitoring as part of a PPM program.

Guidelines for inspection and testing of electrical equipment can be found in the relevant IEEE and ANSI standards documents, in the manufacturer's instruction manuals, in NFPA 70B [B7], and in the standards of the International Electrical Testing Association (NETA) [B6]. It is recommended that these sources be consulted and written checklists and procedures appropriate to the specific types of equipment and the system being assessed be prepared prior to undertaking the initial inspection and testing.

In addition to the inspection of the equipment itself, consider other physical conditions that can affect reliability. Physical construction of switchgear may compromise the independence of components that appear to be completely redundant to each other on the one-line diagram. A significant fraction of electrical equipment failures stem from non-electrical causes such as human activity, physical contamination, and failure of environmental systems, with contamination from leakage of steam, water, or other process fluids leading the list. The physical assessment should address such questions as:

a) Is the installation secure from access by unauthorized or unqualified persons?

b) Do enclosures or locations effectively exclude small animals such as squirrels, snakes, and vermin from entering equipment?

c) Are barriers, such as bollards, provided to protect equipment from vehicles in locations subject to car, truck, or forklift traffic?

d) Are areas around electrical equipment kept clear of storage and other obstacles that interfere with ready access for O&M?

e) Are working clearances in compliance with applicable codes and safe work rules?

f) Is piping and ductwork either kept clear of the equipment, or the equipment protected against leakage by drip-proof enclosures, double-walled piping, or drip pans?

g) Are items of equipment that are redundant to one another provided with segregation to reduce the likelihood of failure in one unit spreading to the other, or of an external event such as mechanical damage, water leakage, or fire affecting both?

h) Are there internal barriers between redundant circuits and buses in switchgear to prevent arcing faults from affecting multiple circuits?

i) Are ventilation, heating, and cooling equipment serving electrical equipment rooms in working order? Are temperatures monitored to promptly detect failure of environmental control?

j) Are air supplies filtered and drawn from areas of the facility that are unlikely to result in exposure of the equipment to high levels of humidity or to conductive or corrosive materials?

k) Are duct-bank, conduit, and busway entries properly sealed against movement of air between the outside environment and the electrical room and switchgear interior?

l) Is the equipment located above potential flood levels? Are there housekeeping pads to keep spillage or leakage of water on the floor out of the equipment?

m) Are there protective guards or covers on operator controls that can cause outages if bumped or brushed against, such as trip switches and emergency power off (EPO) buttons?

n) Are there burnt-out or otherwise inoperative indicator lights on circuit breakers or relay and control panels?

o) Are there relays with targets that have not been reset from past tripping events?

p) Are ground fault detectors provided on ungrounded systems? Do they show any un-cleared faults? Are they remotely monitored?

q) Is metering provided? Is it remotely monitored?

r) Are there provisions for monitoring control and protection circuits and switchgear power supplies to detect conditions such as internal failure or loss of power supply?

s) Is equipment clearly labeled, following a consistent identification scheme? Is labeling up-to-date, or are breakers that are in service still labeled “spare” and breakers that are turned off still labeled with a load designation?

t) Are mimic buses provided on switchgear, switchboards, and control panels?

u) Does the installation readily accommodate maintenance procedures by providing such features as generous working clearances, good light levels, provisions for application of protective grounds, hinged versus bolted access panels, safe access to bolted bus and cable connections for thermography, etc.?

10. Operations and maintenance

The final area of evaluation is O&M practices. An effective PPM program is important to achieving the designed-in reliability of power systems, but this is only one of many aspects of O&M that can affect reliability. Other considerations include commissioning, training, documentation, and spare parts stocking. If an assessment of current O&M practices finds any of these areas lacking, consider the impact on reliability and make improvements. The greatest challenge in this area in most facilities is maintaining a long-term commitment to effective O&M practice in the face of short-term production schedules, cost control measures, and other management pressures. For additional information on the requirements of a maintenance program, refer to IEEE Std 3007.2.

10.1 Electrical acceptance testing and commissioning

Effective electrical acceptance testing and commissioning of power distribution systems and equipment is critical to achieving reliable performance. Electrical acceptance testing verifies the insulation integrity and proper operation of the individual components before energizing the equipment and placing it in service. This includes basic tests such as setting and testing protective relays, dc insulation resistance measurement, ac over-potential withstand, and contact resistance measurement. Commissioning provides an organized and documented process to verify proper installation, electrical integrity, and functional performance in accordance with the manufacturer’s specifications and the design intent by a step- by-step verification of control system operation and system-level functional testing. For additional guidelines for acceptance testing of electrical equipment, refer to the InterNational Electrical Testing Association (NETA) Acceptance Testing Specifications (ATS) [B5].

It is also important that a similar process be in place for commissioning additions and modifications to the system, and recommissioning any control or protection systems involved in the change. An example of this would be the need to retest a bus differential relay circuit when adding additional cubicles to the switchgear.

10.2 Training

The level of training and knowledge of the system on the part of the personnel who operate and maintain it is important to reliability. Human activity is considered a factor in more than half of all failures of critical power systems, and training may be the most effective tool available to reduce these outages. When new systems and equipment are installed, operators should be provided with training, not only from the manufacturer of the equipment itself, but from the designer or the plant engineer on the overall operation of the system and how the individual pieces of equipment function within it. Written system descriptions and operating procedures should be developed and used as the basis for both initial training and periodic retraining. While the installing contractor commonly provides some operator training in the form of a "walk-through" and demonstration, a comprehensive program that includes both classroom and field training components should supplement this. It is increasingly common to videotape or otherwise record initial training sessions to assist in training new employees and retraining existing staff.

10.3 System documentation

Accurate and up-to-date system documentation is another aspect of O&M practice that can significantly affect system reliability.

Accurate one-line diagrams and relay schedules are necessary to assess the extent of the system affected by an outage and to select appropriate switching procedures for restoration of service. All non-emergency switching of the system should follow written switching procedures to minimize the likelihood of errors that result in loss of load. Preparing commonly used switching procedures in advance, such as a clearance procedure for each feeder in the system, can speed operator response and reduce outage durations.

Maintain up-to-date schematic and wiring diagrams and manufacturer's instruction manuals for all equipment either at the equipment location or in a readily accessible and effectively indexed central filing system. This will reduce repair times and decrease the probability of increasing the extent of an outage through inadvertent action by maintenance staff.

The most useful documentation is accurate, concise, and located where needed during switching procedures or response to unplanned outages. Some measures to reduce outages associated with human activity include the following:

a) Post one-line diagrams and operating procedures at the locations of switchgear and control panels.

b) Make sure that labels on equipment correspond to designations on the drawings.

c) Provide clear warning labels on control devices whose operation affects critical loads.

d) Post the names and contact numbers of supervisors, engineering staff, utility dispatchers and emergency services in all electrical rooms. Provide telephones, radios, or other means for rapid communication.

e) Use colors on drawings, mimic buses, and labels to distinguish between different systems and circuits.

10.4 Spare parts levels

Stocking spare parts for electrical distribution equipment can provide higher inherent availability levels associated with short duration "replace with spare" outage times in lieu of much longer times associated with "repair in place" or "procure a replacement." Availability of spares for components requiring periodic preventive

maintenance such as drawout circuit breakers can increase operational availability by reducing outage times associated with such maintenance to the short period required to exchange the breaker requiring maintenance with a spare instead of keeping it out of service for the duration of the maintenance activity.

Consider repair times and commercial availability when determining what parts to stock and in what quantities. Common candidates include, but are not limited to:

- Fuses
- Circuit breakers
- Protective relays
- Transformers
- Cables

Most facilities maintain some stock of replacement fuses on site, but review these stocks to verify that fuses with not only the correct voltage and current ratings, but also the correct time-current characteristics, are located conveniently to the equipment. Loss of selective coordination may result if pressure to return equipment to service leads to use of a fuse with different characteristics than the original, degrading the reliability designed into the system.

It is common to provide spare circuit breakers with the initial installation of drawout switchgear because this type of equipment is usually only selected when the higher availability associated with the ability to disconnect the breakers for maintenance with the bus in service is required. Over time, breakers intended as spares may be used to serve new loads, leading to a reduction in availability. Consider purchasing additional spare breakers to restore the intended availability of the system.

Protective relays have relatively low failure rates and replacements are usually readily available. However, in the case of critical equipment when there are a large number of identical units in the system, there may be benefits to stocking replacements. Where relays have drawout cases, availability of spares can reduce the amount of time circuits are out of service for periodic relay testing as described above for circuit breakers. Where relays are fixed-mounted or relay cases contain functional components other than just terminals and connectors, provide test switches for testing.

Transformer failures are infrequent but typically involve long repair times. In many cases, it is unacceptable to wait for repair to restore service and a replacement, either permanent or temporary, is required. The higher the kVA and the voltage, the longer the time required to procure a replacement is likely to be. Non-standard voltages or winding configurations can also involve long replacement times. Review the installed inventory of transformers with respect to availability of permanent or temporary replacements in determining what to stock. The operators of many industrial and commercial facilities consciously limit the size and types of transformers used on their systems to those that are available from the local utility if a failure occurs.

Evaluate medium voltage cable on a similar basis to transformers. If the time required to obtain replacement cable for a specific circuit failure would extend the outage unacceptably, consider stocking a quantity adequate to replace the longest run in the circuit. Many large facilities standardize on a limited number of medium voltage conductor types and sizes to simplify this stocking. Portable or “drag-line” cables applicable on a temporary basis in any area of the facility may be an economic alternative to stocking multiple sizes of cable. Consider also having spare kits and/or materials for cable splicing and termination available. Some cable termination kits with infrequently used configurations, or designed to interface to non-standard or proprietary bushings, may have extremely long lead times. Consult the manufacturer regarding the shelf life of splicing and termination materials; it may be necessary to replace unused stock periodically to maintain the integrity of the materials.

11. Other vulnerable areas

In many industrial plants, a single component controls the major process. This component may be a rectifier system, a computer, or a control system. The continuity of the electric supply to this controller is just as important to the process as the main machine itself. With the prevalence of digital controls for both manufacturing equipment and facility support equipment such as heating and cooling systems, momentary interruptions may cause control system shutdowns that extend the re-start time for a process or operation significantly. With proper application of energy storage within or external to these systems, typically provided by a battery-based UPS, the controls can remain on line, causing the equipment to go into a "safe-hold" position on power interruption. This continuity is important to note when machining high-value products in a continuous process, such as in the aircraft industry. IEEE Std 3006.7 provides guidance on the design of such continuous power systems.

The "quality" of the electrical environment may also affect the accuracy and efficacy of a computer or a computer-based process. More than just the continuity of the electric supply determines this quality. Voltage dips, line noise, ineffective grounding, extraneous electrical and magnetic fields, temperature changes, and even excessively high humidity can adversely affect the accuracy of a computer or microprocessor. Premature equipment failure can result from voltage that is too high, too low, excessively harmonic laden, or unbalanced, or any combination of these. NEMA and ANSI standards establish recognized voltage tolerances. However, Linders [B4] provides a means to evaluate a situation where more than one area deviates from rating. It is important to periodically record and log voltage levels of all three phases and to determine the harmonic content at strategic locations in the plant's distribution system. The widespread use of solid-state switching devices has increased harmonic content in power systems. Compare harmonic voltage and current levels on the system to the limits in Clause 10 of IEEE Std 519 to determine whether the situation warrants further investigation. However, the engineer must look at harmonic content in conjunction with other criteria to determine whether there is cause for a significant loss of life in equipment. Removing harmful harmonics generally requires filter circuits, and their nature is beyond the scope of this recommended practice.

Another area of importance is the lighting required for operation and personnel safety. A failure in a particular lighting circuit may reduce area lighting to a level below what is necessary to work safely. Evaluation should address:

a) Emergency task lighting and egress lighting
b) Security lighting
c) Multiple circuits per area so that a single outage does not reduce lighting to an unacceptable level

Another important lighting consideration is the fact that some high-intensity discharge lamps require as long as 15 min to restart after a power interruption. Since even minor voltage sags that may not affect production equipment can extinguish this type of lighting, a supplementary source is necessary when these lamps are the primary source of illumination.

Failure of non-electrical systems such as heating, ventilation, and air conditioning (HVAC) and process cooling may affect the electrical system if temperature-sensitive electrical equipment is affected. While failures in these systems are usually mechanical in nature, electrical failures do occur. Fans and pumps are often integral parts of the cooling system in large transformers or rectifier circuits, and loss of coolant circulation could either shut down the equipment or significantly reduce production output. Power electronic equipment such as variable frequency drives and UPS systems depends upon a controlled environment or external cooling source and may shut down thermally on loss of cooling. Therefore, such fans and pumps are a critical part of the system, require effective maintenance, and spare parts may be a wise investment. Space ventilation can also be critical to cooling, and HVAC fans are often neglected—until they fail. Hence, periodic maintenance and/or spare fan motors may be a good investment.

12. Conclusion

The facility engineer should analyze the power distribution system electrically and physically and inquire about the utility's system. In this analysis, the engineer should:

a) Assess the configuration of the system for its ability to provide the reliability required by the loads.

b) Evaluate the age and condition of the system from the utility and throughout the plant to determine if the equipment is vulnerable to premature failure.

c) Determine the reliability and availability of power supplied by the utility and any on-site generation.

d) Verify that the system is selectively coordinated such that faults in other parts of the system do not affect critical loads.

e) Analyze vulnerable areas and evaluate the need for special restoration equipment, spare parts, or procedures.

f) Based on probability and economic analysis, make capital or preventive maintenance investments as indicated by the analysis.

g) Make and document contingency plans.

h) Develop operation, maintenance, and documentation procedures to support continuous optimum reliability performance of the facility.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] Dorr, D.S., "Point of Utilization Power Quality Results," National Power Laboratory—BEST Technologies, Neenah, WI.

[B2] IEEE Committee Report, "Report on Reliability Survey of Industrial Plants," Parts I–VI, *IEEE Transactions on Industry Applications*, vol. IA-1 0, March/April, pp. 213–252, July/August, pp. 456–476, September/October 1974, p. 681.

[B3] Lee, R., "New Developments in Cable System Testing," IEEE Transactions on Industry Applications, vol. IA-1, p. •••, May/June 1977.[5,6]

[B4] Linders, J. R., "Effects of Power Supply Variations on AC Motor Characteristics," IEEE Transactions on Industry Applications, vol. IA-8, July/August, pp. 383–400, 1972, http://dx.doi.org/10.1109/TIA.1972.349827.

[B5] NETA Acceptance Testing Specifications (ATS), InterNational Electrical Testing Association, Portage, MI.

[B6] NETA Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems (MTS), InterNational Electrical Testing Association, Portage, MI.[7]

[B7] NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.[8]

[B8] USDA Rural Utilities Service Bulletin 1730A–119, Interruption Reporting and Service Continuity Objectives for Electric Distribution Systems, 24 March 2009.

[5]IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08854, USA (http://standards.ieee.org/).
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